Study of ATLAS Sensitivity to FCNC Top Quark Decay $t \to Zq$

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ABSTRACT

The sensitivity of ATLAS experiment to the top-quark rare decay via flavor-changing neutral currents $t \to Zq$ (q represents c and u quarks) have been studied at $\sqrt{s}$=14 TeV in two decay modes: 1.The pure leptonic decay of gauge bosons: $t\bar{t} \to ZqWb \to l^+l^-jl^\pm\nu j_b$, (l=e, μ). 2.The leptonic decay of Z bosons and hadronic decay of W bosons: $t\bar{t} \to ZqWb \to l^+l^-jjjj_b$, (l=e, μ). The dominant backgrounds Z+jets, ZW and $t\bar{t}$ has been analysed. The signal and backgrounds were ganarated via PYTHIA 5.7, simulated and analysed using ATLFAST 2.14. A branching ratio for $t \to Zq$ as low as 1.1x10^{-4} for the leptonic mode and 2.3x10^{-4} for hadronic mode could be discovered at the 5σ level with an integrated luminosity of 10^5 pb$^-$1.

1.Introduction

The existence of the top quark has been established at the Fermilab Tevatron by the CDF and DO Collaborations [1]. Because the top quark is heavier than all other observed fermions and gauge bosons and has a mass of the order of the Fermi scale, it couples to electroweak symmetry breaking sector strongly. If anomalous top quark couplings beyond the Standard Model (SM) were to exist, they would affect top quark production and decay processes at hadron and $e^+ \, e^-$ colliders [2,3]. Therefore to study the flavour-changing neutral current top quark decay $t \rightarrow Zq$ (q represents either c or u quarks) is of great interest, as known [4,5] that LHC can be considered as "top factory", because about 80 000 $t\bar{t}$ events are expected to be produced per day at $L = 10^{33} \; cm^{-2} \; s^{-1}$, that's why the LHC with high integrated luminosity and energy have good potential to explore this rare decay.

We study the sensitivity of ATLAS experiment to the Branching ratio of top-quark rare decay mode $t \rightarrow Zq$ $(q = u, c)$. In the framework of the Standard Model the loop suppression and heaviness of gauge bosons makes this process rare being of an order of 10^{-13} [6]. Meanwhile the other models predict significantly larger Branching ratios for this process. Two-Higgs-doublet model predicts for Br($t \rightarrow Zq$)$\sim 10^{-9}$ [7] and Super symmetric (SUSY) model (without R-parity) - Br($t \rightarrow Zq$)$\sim 10^{-4}$ [8]. The existing limit at 95 % CL from CDF [9] is Br($t \rightarrow Zq$) $< 33\%$ (RUN1 at the Tevatron). The observation of such a top-quark decay mode would signal to existance of new physics - the physics beyond the SM: new dynamical interactions of top quark, multi-Higgs doublets, exotic fermions and etc. [5,6,7] In addition this mode is of great interest since $t\bar{t} \rightarrow ZZ + cc$ decays would prove to be serious background to events containing Z boson pairs and jets from cascade decays of squarks and gluinos [10].

The dominant mechanisms for top quarks production at LHC are $q\bar{q}$ and gg annihilation channels $q\bar{q}$, $gg \rightarrow t\bar{t}$. The final state topology of $t\bar{t} \rightarrow ZqWb$ has two decay mode of gauge bosons:

1. The pure leptonic decay of gauge bosons:

$t \rightarrow Zq \rightarrow l^+ l^- j$, $\bar{t} \rightarrow Wb \rightarrow l^{\pm} \nu j_b$ (l=e, μ)

2. The leptonic decay of Z bosons and hadronic decay of W bosons:

$t \rightarrow Zq \rightarrow l^+ l^- j$, $\bar{t} \rightarrow Wb \rightarrow jjj_b$ (l=e, μ)

The value of the Branching ratio of hadronic mode is three times more than the leptonic one, but it has enormous QCD-backgrounds at hadron collider while the pure leptonic has a very distinct experimental signature: three isolated charged leptons, two of which

reconstruct a Z, a large missing transverse momentum (P_T^{miss}) and two hard jets coming from the b and q ($q = c, u$) quarks.

The both channels are of great interest.

2.The Signal Generation

As was mentioned above the dominant source of top quark production at hadron colliders are $q\bar{q}$, $gg \to t\bar{t}$ processes. The PYTHIA 5.7 was set up to produce $t\bar{t}$ events at $\sqrt{s} = 14$ TeV and $m_{top} = 174$ GeV with proton structure functions CTEQ2L. Initial and final state QED and QCD (ISR, FSR) radiation, multiple interactions, fragmentations and decays of unstabled particles were enabled, but the underlying event (beam remnants, pile up etc) was switched off.

The generation of the channel $t \to Zq$ is not implemented in the PYTHIA. This process had been included into PYTHIA in the following way: all individual decay channels of top quark had been switched off except of the $t \to Wb$ and $t \to Ws$ ones. In the channel $t \to Ws$ the decay $t \to Zq$ was included replacing W by Z and s by $c(u)$.

3.The Leptonic Decay Mode

The signature for the pure leptonic decay mode as mentioned above is $t\bar{t} \to ZqWb \to l^+l^-jl^\pm j_b$. Due to the requirement of three isolated charged leptons, two of which reconstruct a Z and a large missing transverse energy the following SM backgrounds has been considered:

- $Z(\to ll) + jets$
- $pp \to W^\pm Z + X \to l^\pm \nu l^+ l^- + X$
- $t\bar{t} \to W^+ b W^- \tilde{b} \to l^+ \nu j_b l^- \tilde{\nu} j_b$.

The main goal is to analyse fully generated events and select the isolated leptons, reconstruct jets, identify b-jets and estimate the missing transverse energy. A parametrization of electron, muon momentum energy resolution is included, as well as a parametrization of the hadronic calorimeter energy resolution (for jets) and the effect of the ATLAS magnetic field on jet reconstruction. For this purpose some subroutines from the fast

simulation package ATLFAST 1.0 have been used [11]. For the leptons isolation only tracking isolation method had been considered. The jets momenta had been recalibrated by the calibration factor $K_{jet} = P_T^{parton}/P_T^{jet}$ according to the algorithm of the ATLFAST package, where P_T^{parton} denotes the transverse momentum P_T of the parton which initiated the jet (before FSR).

Some preselection cuts were applied to signal and backgrounds before writing the events on DST:

1. The event contains at least 3 leptons (electrons with $P_T > 5$ GeV and muons with $P_T > 6$ GeV) within pseudorapidity $|\eta| < 2.5$.
2. The events must contain a pair of opposite sign and same flavour leptons compatible with them having come from Z bosons.
3. The number of jets in the event $N_{jet} \geq 2$ with $P_T^{jet} > 15$ GeV.

The $Z(\to ll) + jets$ background in the final state also have a pair of isolated charged leptons, but P_T^{miss} in such processes arises mainly from neutrinos produced in semileptonic decays of heavy quarks.

$Z(\to ll) + jets$ production at LHC has relatively large cross section dominated by $qg \to Zq$ and $q\bar{q} \to Zg$ processes. To speed up the generation, the thresholds on invariant mass $\hat{m} = \sqrt{\hat{s}}$ and transverse momentum $\hat{p_\perp}$ had been imposed: $\hat{m} = \sqrt{\hat{s}} > 130$ GeV; $\hat{p_\perp} > 50$ GeV. So we collect events mainly from the top peak (otherwise we would have additional large contribution from undesireble events). The cross section for this sample of events is σ_{Z+jets}=3186 pb. The demand of three isolated leptons and large P_T^{miss} reduces this background significantly.

The ZW background is the electroweak process $pp \to W^\pm Z + X \to l^\pm \nu l^+ l^- + X$. σ_{ZW}=26.58 pb. Since the signal events naturally contain two energetic jets from heavy top quark decays, typically with a transverse momentum of order $P_T(j) \simeq 1/2m_t(1-M_w^2/m_t^2)$, [5] to demand of two observable jets in the events one of which is b-jet, reduces the WZ background significantly.

In the selected $t\bar{t}$ background events sources of leptons are arising from the decays of $W^\pm$ and from cascade decays, where quarks initially decay hadronically, but produce leptons further in the decay chain. These cascade leptons have a softer P_T spectrum than the leptons from W and requirement of three isolated leptons with high P_T reduce $t\bar{t}$ background significantly. We have to emphasize, that $t\bar{t}$ background suffers from the demand of the existence only one tagged b- jet in the event.

The number of events collected over a given period of time is calculated by the formula:

$$N = \sigma \cdot L \tag{1}$$

where L is the integrated luminosity ($L = 10^5\ pb^{-1}$). The expected number of events N_{exp} are:

• for the signal

$$N^S_{exp} = 2 \cdot \sigma_{t\bar{t}} \cdot Br(t \to Zc) \cdot Br(t \to Wb) \cdot Br(W \to l\nu) \cdot Br(Z \to ll) \cdot L \quad (2)$$

$$N^S_{exp} = 22.8 \cdot Br(t \to Zc) \cdot L$$

the estimation has been done for $\sigma_{t\bar{t}}$=800 pb [12].

• for $Z(\to ll) + jets$ background

$$N^{Z+jets}_{exp} = 21400000$$

• for ZW background

$$N^{ZW}_{exp} = 40000$$

• for $t\bar{t}$ background

$$N^{t\bar{t}}_{exp} = \sigma_{t\bar{t}} \cdot (Br(W \to l\nu))^2 \cdot (Br(t \to Wb))^2 \cdot L \quad (3)$$

$$N^{t\bar{t}}_{exp} = 3720000$$

Two sets of kinematical cuts had been applied in sequence for the signal and backgrounds (see Tables 1÷9).

	S E T 1	S E T 2
Lepton isolation cut:	$\Delta R = 0.2$	$\Delta R = 0.3$
Lepton P_T cut:	3l with $P^l_T > 20\ GeV$ in $\vert\eta^l\vert < 2.5$	
E_T missing:	$E^{miss}_T > 30\ GeV$	
jets η cut:	jets with $\vert\eta^{jet}\vert < 2.5$	
2 jets P_T cut:	2jets with $P^{jet}_T > 40\ GeV$	
	2jets with $P^{jet}_T > 50\ GeV$	
jets isolation cut:	$\Delta R_{jj} > 0.4$	
Lepton-jets isolation cut:	$\Delta R_{lj} > 0.4$	
Z mass cut:	$M_Z \pm 6\ GeV$	
b jets cut:	one tagged b jet in the event	
Top mass cut:	$M_{Zq} \pm 8\ GeV$, $M_{Zq} \pm 12\ GeV$, $M_{Zq} \pm 24\ GeV$	

For the lepton tracker (tracking) isolation it had been assumed that there be no track with $P_T > 2\ GeV$ in cone $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$. It have been considered two cones of $\Delta R:\ \Delta R = 0.2$ (SET1) and $\Delta R = 0.3$ (SET2).

The requirement of 3 leptons on the level of preselection cuts reduces significantly Z+jets and $t\bar{t}$ backgrounds, meanwhile the requirement of two jets reduces significantly ZW and Z+jets backgrounds.

The efficiency of preselection cuts for signal is 80%, while for the large number expected events Z+jets background is 1.7%. After applying the preselection cuts other backgrounds are rejected (ZW background by $\sim$ 90% and $t\bar{t}$ by $\sim$ 80%) significantly.

In Tables 1÷8 three leptons identification efficiency ($(0.9)^3 = 0.729$) have not been taken into consideration, but for the estimation of the Branching ratios it have been done.

Three leptons isolation cut reduces signal by $\sim$ 15 % for SET1 and by $\sim$ 23 % for SET2. Thus for SET2 the signal reduction is more by $\sim$ 10 % than for SET1. The ZW background is not affected by lepton isolation cut. This background reduces only by $\sim$ 3÷4 % for both SETs. In Z+jets and $t\bar{t}$ backgrounds two islolated leptons are present and the third lepton originates from the cascade decays. The requirement of three isolated leptons affects most significantly these backgrounds, about 90 ÷ 95 % of events respectively for set1 and set2 are rejected.

The requirement of three leptons with $P_T^l > 20\ GeV$ in $|\eta^l| < 2.5$ reduces signal and ZW background by about 30 %. In Z+jets and $t\bar{t}$ backgrounds this cut remains about 4 % of events. This is well illustrated in Figs.1 and 2. Fig.1 presents the P_T distribution of two leptons that reconstruct Z invariant mass for signal and backgrounds and Fig.2 shows the P_T distribution of third lepton respectively. The arrows in Figs. 1 and 2 indicate the threshold P_T for leptons $P_T^l = 20\ GeV$.

After applying $P_T^{miss} > 30\ GeV$ cut in signal, ZW and $t\bar{t}$ backgrounds remain 76 %, 70 % and 90 % of events, which were accepted by the previous cut, whereas for Z+jets remain only $\sim$ 8 % of events. Thus the P_T^{miss} cut reduces significantly Z+jets background (see Fig.3., arrow indicates the threshold $P_T^{miss} = 30\ GeV$).

It have been demanded the presence of two jets in $|\eta^{jet}| < 2.5$ satisfying to the following conditions of isolation: $\Delta R_{jj} > 0.4$ (jet-jets isolation) and $\Delta R_{lj} > 0.4$ (lepton-jets isolation). Two threshold values for P_T^{jet} cut have been examined: $P_T^{jet} > 40\ GeV$ and $P_T^{jet} > 50\ GeV$ (see Tables 1÷9). Fig.4 presents the number of jets with $P_T^{jet} > 50\ GeV$ in an event. One can see, that the cut requiring the presence of 2 and more jets in each event is a major rejector for the ZW background.

The kinamatic variable which can be used to seperate signal from backgrounds is the

reconstructed Z mass (since there is no Z in the $t\bar{t}$ background). For the reconstruction of Z mass, have been required a pair of isolated leptons within $M_Z \pm 6\ GeV$ mass window. The choice of 6 GeV for this cut is motivated mainly by the resolution ($\sim\ 2\sigma$) on the reconstructed Z in the signal. Fig 5.a presents distribution of reconstructed invariant mass of ll pairs m_{ll}, for all combinations of ll for the signal. The Z mass cut does not affect strongly the ZW and Z+jets backgrounds . Meanwhile this cut is very effective tool for the suppression of $t\bar{t}$ background. After applying this cut only 10÷12 % of events accpeted by previous cut retain for SET1 and $P_T^{jet} > 40\ GeV$ and only 5÷7 % of events for SET2 and $P_T^{jet} > 50\ GeV$.

The next demand is the presence in the event only one tagged b jet. After this cut in signal survive 50 % of events accepted by Z mass cut for both SETs and P_T^{jet} criteria whereas for $t\bar{t}$ background this value is smaller by about 10÷20 %. For ZW background the one tagged b jet cut is effective rejector, after applying this cut survive 7÷8 % of events in SET1 and $P_T^{jet} > 40\ GeV$ and 7÷15 % of events in SET2 and $P_T^{jet} > 50\ GeV$ and . The Z+jets background is less affected by b jet cut, 60÷70 % of events are retained. (see Fig.6)

Since the Z+jets and ZW backgrounds do not contain top quark, applyment of $t \to Zq$ mass cut is very useful for the rejection of Z+jets and ZW backgrounds. In Fig. 5.b the distribution of reconstructed invariant top mass m_{llj} (in reconstruction b-jet does not participate) for all combinations of llj for the signal is presented. The resolution σ of m_{llj} is σ=14. The reconstruction of top mass have been required within three mass windows: m_{Zq} ±8 GeV (narrow cut), m_{Zq} ±12 GeV ($\sim\ \sigma$) m_{Zq} ±24 GeV ($\sim\ 2\sigma$). The top mass cut suppressed strongly Z+jets and ZW backgrounds, in m_{Zq} ±8 GeV mass window Z+jets have been vanished.

We suppose that new physics will be discovered if the signal significance is $S/\sqrt{B} \geq 5$. The $S/\sqrt{B}$ is computed as $S/\sqrt{B} = N_S/\sqrt{\Sigma N_B}$, where ΣN_B is the sum over the all observed backgrounds events, N_S – is the number of observed events for the signal

$$N_S = N_{exp}^S \cdot \epsilon_l \cdot \epsilon^S$$

the lepton identification efficience is $\epsilon_l = 90\%$ and ϵ^S is the signal efficiency.

The Branching ratio for the t → Zq decay is expressed by the following formula:

$$Br(t \to Zq) = K \cdot \sqrt{\Sigma N_B}/\epsilon^S \qquad (4)$$

where K=2.52 $\cdot\ 10^{-6}$. The estimated Branching ratios for the leptonic mode for two sets of kinematical cuts and $P_T^{jet} > 40\ GeV$ and $P_T^{jet} > 50\ GeV$ are presented in Table 9. One can see from Table 9, that for the estimation of Branching ratios more optimal is

$P_T^{jet} > 50\ GeV$ cut. In each m$_{Zq}$ mass window the estimated Branching ratios for the both SETs are less for $P_T^{jet} > 50\ GeV$ than for $P_T^{jet} > 40\ GeV$. In this channel, a value of Br(t $\rightarrow$ Zq) as low as 1.1x10^{-4} could be discovered at the 5σ level with an integrated luminosity 10^5 pb^{-1}.

The Branching ratio sensitivity for $t \rightarrow Zq$ leptonic mode have been estimated by Columbia University group [13] for a small statistic at 10^4 pb^{-1} luminosity. Their results are in a good agreemnet with our ones.

2.The Hadronic Decay Mode

The hadronic decay mode of the channel $t \rightarrow Zc$ had been studied by a fast simulation package ATLFAST 2.14. The basic information of the detector geometry is used by this package: the η coverage for the calorimetry, the size of the barrel/endcap transition region for the electromagnetic calorimeter and the granularity of the calorimeters. No effects related for the detailed shapes of particle showers in the calorimeters, for the charged track multiplicity in jets, etc are taken into account. The main goal of the ATLFAST package is to simulate and analyse fully generated events and select isolated leptons, reconstructed jets, label b-jets, c-jets and estimate the missing transverse energy. A more or less accurate parametrization of leptons momentum resolution is included, as well as a parametrization of the hadronic calorimeter energy resolution and the effect of the ATLAS magnetic field on jet reconstruction. For the generation of a processes the ATLFAST uses the generator PYTHIA 5.7. The routines of ATLFAST-B rundomly simulate b, c jets tagging and provide jet energy recalibration. In our case the events have been simulated with ATLFAST and analysed the results using the ATLFAST-B utilities whenever.

For recalibration of light jets momenta we have considered two calibration factors: 1) $K_{jet} = P_T^{q(q=c,u)}/P_T^{jet}$ 2) $K_{jet} = P_T^{parton}/P_T^{jet}$ where P_T^{parton} represents transverse momenta of light quarks originated from $W \rightarrow qq$ decay. The first factor is used for top invariant mass reconstruction m_{llj} and the second one for W invariant mass m_{jj} calculation.

The $t\bar{t}$ events had been generated at $\sqrt{s} = 14$ TeV and $m_{top} = 175$ GeV with proton structure functions CTEQ2L. Initial and final state QED and QCD (ISR, FSR) radiation, multiple interactions, fragmentations and decays of unstabled particles were enabled as for leptonic mode.

The signal $t\bar{t} \rightarrow ZcWb \rightarrow l^+l^-jjj_b$ signature for hadronic mode is: two isolated

charged leptons, which reconstruct Z and 4 energetic jets.

This mode has the following backgrounds:

• $Z(\rightarrow ll) + jets$

• $pp \rightarrow W^{\pm}Z + X \rightarrow jjl^{+}l^{-} + X$

• $t\bar{t} \rightarrow W^{+}bW^{-}\tilde{b}$ final state topology:

a) $l^{+}\nu j_{b}l^{-}\tilde{\nu}j_{b}$

b) $jjj_{b}jjjb$

c) $l^{\pm}\nu j_{b}jjj_{b}$

In case of a) decay additional two jets are QCD jets and in b) and c) items the source of leptons is cascade decays. Therefore if we demand two isolated energetic leptons and four jets among which only one b-jet is required, $t\bar{t}$ background is significantly suppressed. A few survived events vanish on the level of m_{jj} and m_{jjb} invariant masses reconstructions.

To speed up the generation of Z+jets background the same thresholds as in the case of the leptonic mode, has been imposed on invariant mass $\hat{m} = \sqrt{\hat{s}}$ and transverse momentum $\hat{p_{\perp}}$.

The following preselection cuts were applied to signal and background before writing the events on DST:

1. The event contains at least 2 leptons (electrons with $P_T > 5$ GeV within pseudorapidity $|\eta| < 2.5$ and muons with $P_T > 6$ GeV within pseudorapidity $|\eta| < 2.4$).

2. The events must contain a pair of opposite sign and same flavour leptons compatible with them having come from Z bosons.

3. The number of jets in event $N_{jet} \geq 4$ with $P_T^{jet} > 15$ GeV.

The expected number of events N_{exp} for hadronic mode are:

• for ZW background

$$N_{exp}^{ZW} = 121000$$

After preselection cuts the following kinematical cuts had been applied in sequence for the signal and backgrounds:

Lepton P_T cut:	2l with $P_T^l > 20\ GeV$ in $\|\eta^l\| < 2.5$ for e^+,e^- and in $\|\eta^l\| < 2.4$ for μ^+, μ^-
jet P_T cut:	4 jets with $P_T^{jet} > 50\ GeV$ in $\|\eta^l\| < 2.5$
jets isolation cut:	$\Delta R_{jj} > 0.4$
Lepton-jets isolation cut:	$\Delta R_{lj} > 0.4$
Z mass cut:	$M_Z \pm 6\ GeV$
W mass cut:	$M_W \pm 16\ GeV$
b jets cut:	only one tagged b jet in the event
t→W^+b mass cut:	$M_{Wb} \pm 8\ GeV$
t→Zq mass cut:	$M_{Zq} \pm 8\ GeV$, $M_{Zq} \pm 12\ GeV$, $M_{Zq} \pm 24\ GeV$

The number of accepted events and efficiencies (%) of each of these cuts in sequence for signal and backgrounds are presented in Tables 10÷12. After preselection cuts 46 % of events are accepted for signal, while for Z+jets background – 3.5 % and for ZW – 4.1 %. The requirement of two isolated leptons with $P_T^l > 20\ GeV$ in $|\eta^l| < 2.5$ does not affect the signal and backgrounds. After this cut 80 – 90 % of events are survived.

The demand of four jets with with $P_T^{jet} > 50\ GeV$ in $|\eta^l| < 2.5$ strongly reduces Z+jets and ZW backgrounds. In Z+jets 11 % of events accepted by the previous cut are retained and in ZW – 9 %. The jets isolation and lepton-jets isolation cuts does not reduce the signal and backgrounds, 98 –99 % of events are retained.

For the reconstruction of Z mass, have been required the same mass windows as for the leptonic mode. Fig.7.a presents the distribution of reconstructed invariant mass of ll pairs m_{ll} for the best combinations of ll for the signal. The resolution of the reconstructed Z mass is σ=2.91 GeV. Thus mass window ±6 GeV corresponds to $\sim\ 2\sigma$. After applying Z mass cut, in signal and Z+jets background 85 % of events accepted by the previous cut are retained. In ZW background survived 74 % of events from those accepted by the lepton-jets isolation cut.

In hadronic mode the additional kinematical variable which can be used to seperate signal from backgrounds is the reconstructed W mass. For the reconstruction of W mass, have been required a pair of jets within $m_{jj} \pm 16\ GeV$ mass window. The jets that reconstruct the best combinations of W invariant mass, do not participate in further reconstructions. Fig.8.a shows the distribution of reconstructed invariant mass of jets pairs m_{jj} for the best combinations of jj for the signal. The resolution $\sigma_{m_{jj}} = 8$ GeV. Thus the mass window ± 16 GeV corresponds to 2σ of the reconstructed W in the signal. The W mass cut strongly suppresses Z+jets background (since there is no W in this background). Only 28 % of events survive after W mass cut in this background.

The requirement of only one tagged b-jet in the event does not affect the signal, whereas suppresses the Z+jets (retained 6 % of events) and ZW backgrounds (survived 8 % of events).

The reconstructed top mass t→Wb cut is used to reduce Z+jets and ZW backgrounds. In Fig.8.b the distribution of the reconstructed invariant top mass (t→Wb) m_{jjj_b} for the best combinations of jjj_b for the signal is presented. The resolution of m_{jjj_b} is $\sigma_{m_{jjj_b}}$ =18.5 GeV. For the reconstruction of t→Wb mass narrow cut window have been chosen $m_{Wb} \pm 8\ GeV$. After applying the t→Wb mass cut in signal survived 25 % of events accepted by the b - jet cut. This cut strongly suppresses Z+jets background, 6 % of events are retained after this cut and in ZW background accepts only one event.

For the reconstruction of top mass t→Zq have been chosen the same mass windows as for the leptonic mode: m_{Zq} ±8 GeV (narrow cut), m_{Zq} ±12 GeV ($\sim\ \sigma$) m_{Zq} ±24 GeV ($\sim\ 2\sigma$). After applying this cut to the signal, in mass window m_{Zq} ±8 GeV are retained 43 % of events accepted by the t→Wb cut, in m_{Zq} ±12 GeV – 55 % and in m_{Zq} ±24 GeV – 70 %. It is worth to mention, that in mass window m_{Zq} ±8 GeV 91 % of events are reconstructed by c jets , t→ llj_c and only 10 % of events are reconstructed by light jets. By the widening the mass window the mixture of events reconstructed by light jets increases from 10 % to 22 %, but the number of events reconstructed by c-jets increases too. The Z+jets background in mass window m_{Zq} ±8 GeV vanishes and one event is accepted in m_{Zq} ±12 GeV and two events in m_{Zq} ±24 GeV. This cut completely suppresses the ZW background in all mass windows. In Fig.7.b the distribution of reconstructed t→Zq invariant top mass m_{llj} for the best combinations of llj is presented for the signal. The resolution σ of m_{llj} distribution is $\sigma_{m_{llj}} = 9.9$ GeV.

In Table 13 are presented relative efficiences in % of some important kinamatical cut for leptonic and hadronic modes of the signal for the comparison. One can see, that the relative efficiences of leptons, jets , Z mass , b jet and top mass cuts for leptonic and hadronic modes coincide, as it was expected.

The Branching ratios for the hadronic mode have been estimated by the formula (4), where for hadronic mode K=6.87 $\cdot$ 10^{-7}. The results are presented in Table 14. In hadronic mode, a value of Br(t $\rightarrow$ Zq) as low as 2.2 $\div$ 2.3x10^{-4} could be discovered at the 5σ level with an integrated luminosity 10^5 pb^{-1}.

Combining the results from the leptonic and hadronic modes a Branching ratios have been estimated for t→Zq. For the estimation the following formula was used:

$$Br(t \rightarrow Zq) = K \cdot \sqrt{\Sigma N_B}/(0.216 \cdot \epsilon^L + 0.676 \cdot \epsilon^H) \tag{5}$$

where ϵ^L is the signal efficiency for the leptonic mode, ϵ^H is the signal efficiency for the

hadronic mode and K=4.65 $\cdot$ 10^{-6}. The results for the combined leptonic and hadronic modes are presented in Table 15. One can see from the Table, that a Branching ratio for t $\rightarrow$ Zq as low as 0.9x10^{-4} could be discovered at the 5σ level with an integrated luminosity 10^5 pb^{-1}.

3. Conclusions

We have studied the sensitivity to the top quark rare decay via flavour-changing neutral currents $t \to Zq$ ($q = u, c$) at LHC on the ATLAS experiment for the luminosity $L = 10^5\ pb^{-1}$. The Branching ratios of $t \to Zq$ in pure leptonic and hadronic decay modes had been estimated. The results demonstrate, that in the leptonic mode a Branching ratio as low as 1.1x10^{-4} and in the hadronic mode as low as 2.2 $\div$ 2.3x10^{-4} could be discovered at the 5σ level with an integrated luminosity 10^5 pb^{-1}. Combining the results from the leptonic and hadronic modes, a Branching ratio for $t \to Zq$ as low as 0.9x10^{-4} could be discovered at the 5σ level.

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FIGURE CAPTIONS

Fig.1. The P_T distributions of leptons that recostruct Z mass ,for leptonic mode signal and backgrounds, normalised to unity. The arrow indicates the threshold value P_T^l for kinematical cut.

Fig.2. The third lepton P_T distributions for leptonic mode signal and backgrounds, normalised to unity. The arrow indicates the threshold value P_T^l for kinematical cut.

Fig.3. The reconstructed P_T^{miss} distributions for leptonic mode signal and backgrounds, normalised to unity. The arrow indicates the threshold value P_T^{miss} for kinematical cut.

Fig.4. Distribution of jet multiplicity (threshold at $P_T^{jet} > 50\ GeV$) for signal and backgrounds, normalised to unity. The arrow indicates the threshold value of the number of jets for kinematical cut.

Fig.5. a) Distribution of reconstructed invariant mass of the lepton pairs, M_{ll} for the leptonic mode. b) Distribution of reconstructed invariant mass of $t \to llj$ for the leptonic mode.

Fig.6. Distribution of b-jet multiplicity (threshold at $P_T^{jet} > 50\ GeV$) for signal and backgrounds, normalised to unity.

Fig.7. a) Distribution of reconstructed invariant mass of the lepton pairs, M_{ll} for the best combination (hadronic mode). b) Distribution of reconstructed invariant mass of $t \to llj$ for the best combination of llj (hadronic mode).

Fig.8. a) Distribution of reconstructed invariant mass of the jet pairs, M_{jj} for the best combination (hadronic mode). b) Distribution of reconstructed invariant mass of $t \to jjj_b$ for the best combination of jjj_b (hadronic mode).

Table 1. The numbers of events and efficiencies (%) of kinematical cuts applied in sequence for the signal (leptonic mode) for $P_T^{jet} > 40$ GeV

C U T S	S E T 1		S E T 2	
	Events	Effic. (%)	Events	Effic. (%)
Number of generated events	20565		20565	
Preselection cuts	16497	80.2	16497	80.2
Lepton isolation cut: No track with $P_T > 2\ GeV$ in cone $\Delta R = 0.2$ (SET1); $\Delta R = 0.3$ (SET2)	14071	68.4	12672	61.6
3l with $P_T^l > 20\ GeV$ in $\|\eta^l\| < 2.5$	9844	47.9	8885	43.3
$P_T^{miss} > 30\ GeV$	7462	36.3	6730	32.7
2 jets with $\|\eta^{jet}\| < 2.5$	7021	34.1	6307	30.7
2 jets with $P_T^{jet} > 40\ GeV$	6213	30.2	5552	27.0
jets isolation: $\Delta R_{jj} > 0.4$	6179	30.1	5522	26.8
Lepton-jets isolation: $\Delta R_{lj} > 0.4$	5573	27.1	5138	24.9
Z mass $M_Z \pm 6\ GeV$	4717	22.9	4347	22.1
one tagged b jet in the event	2367	11.5	2193	10.7
t→Zq mass : $M_{Zq} \pm 8\ GeV$	1038	5.1	970	4.7
t→Zq mass : $M_{Zq} \pm 12\ GeV$	1389	6.8	1294	6.3
t→Zq mass : $M_{Zq} \pm 24\ GeV$	1879	9.1	1742	8.5

Table 2. The numbers of events and efficiencies (%) of kinematical cuts applied in sequence for the signal (leptonic mode) for $P_T^{jet} > 50$ GeV

C U T S	S E T 1		S E T 2	
	Events	Effic. (%)	Events	Effic. (%)
Number of generated events	20565		20565	
Preselection cuts	16497	80.2	16497	80.2
Lepton isolation cut: No track with $P_T > 2\ GeV$ in cone $\Delta R = 0.2$ (SET1); $\Delta R = 0.3$ (SET2)	14071	68.4	12672	61.6
3l with $P_T^l > 20\ GeV$ in $\lvert\eta^l\rvert < 2.5$	9844	47.9	8885	43.3
$P_T^{miss} > 30\ GeV$	7462	36.3	6730	32.7
2 jets with $\lvert\eta^{jet}\rvert < 2.5$	7021	34.1	6307	30.7
2 jets with $P_T^{jet} > 50\ GeV$	4904	23.8	4341	21.1
jets isolation: $\Delta R_{jj} > 0.4$	4881	23.7	4322	21.0
Lepton-jets isolation: $\Delta R_{lj} > 0.4$	4453	21.6	4063	19.8
Z mass $M_Z \pm 6\ GeV$	3781	18.4	3450	16.8
one tagged b jet in the event	1835	8.9	1678	8.2
t→Zq mass : $M_{Zq} \pm 8\ GeV$	787	3.8	728	3.5
t→Zq mass : $M_{Zq} \pm 12\ GeV$	1053	5.1	973	4.7
t→Zq mass : $M_{Zq} \pm 24\ GeV$	1383	6.7	1264	6.1

Table 3. The numbers of events and efficiencies (%) of kinematical cuts applied in sequence for the Z+jets background (leptonic mode) for $P_T^{jet} > 40$ GeV

C U T S	S E T 1		S E T 2	
	Events	Effic. (%)	Events	Effic. (%)
Number of generated events	$21.4{\cdot}10^6$		$21.4{\cdot}10^6$	
Preselection cuts	366843	1.7	366843	1.7
Lepton isolation cut: No track with $P_T > 2\ GeV$ in cone $\Delta R = 0.2$ (SET1); $\Delta R = 0.3$ (SET2)	40472	0.19	21539	0.10
3l with $P_T^l > 20\ GeV$ in $\lvert\eta^l\rvert < 2.5$	1644	$7.7{\cdot}10^{-3}$	945	$4.4{\cdot}10^{-3}$
$P_T^{miss} > 30\ GeV$	129	$6.0{\cdot}10^{-4}$	80	$3.7{\cdot}10^{-4}$
2 jets with $\lvert\eta^{jet}\rvert < 2.5$	122	$5.7{\cdot}10^{-4}$	80	$3.7{\cdot}10^{-4}$
2 jets with $P_T^{jet} > 40\ GeV$	97	$4.5{\cdot}10^{-4}$	56	$2.6{\cdot}10^{-4}$
jets isolation: $\Delta R_{jj} > 0.4$	94	$4.4{\cdot}10^{-4}$	56	$2.6{\cdot}10^{-4}$
Lepton-jets isolation: $\Delta R_{lj} > 0.4$	59	$2.8{\cdot}10^{-4}$	38	$1.8{\cdot}10^{-4}$
Z mass $M_Z \pm 6\ GeV$	45	$2.1{\cdot}10^{-4}$	28	$1.3{\cdot}10^{-4}$
one tagged b jet in the event	28	$1.3{\cdot}10^{-4}$	21	$9.8{\cdot}10^{-5}$
t→Zq mass : $M_{Zq} \pm 8\ GeV$	0	0	0	0
t→Zq mass : $M_{Zq} \pm 12\ GeV$	1	$4.8{\cdot}10^{-6}$	1	$4.8{\cdot}10^{-6}$
t→Zq mass : $M_{Zq} \pm 24\ GeV$	2	$9.3{\cdot}10^{-6}$	1	$4.8{\cdot}10^{-6}$

Table 4. The numbers of events and efficiencies (%) of kinematical cuts applied in sequence for the Z+jets background (leptonic mode) for $P_T^{jet} > 50$ GeV

C U T S	S E T 1		S E T 2	
	Events	Effic. (%)	Events	Effic. (%)
Number of generated events	$21.4{\cdot}10^6$		$21.4{\cdot}10^6$	
Preselection cuts	366843	1.7	366843	1.7
Lepton isolation cut: No track with $P_T > 2\ GeV$ in cone $\Delta R = 0.2$ (SET1); $\Delta R = 0.3$ (SET2)	40472	0.19	21539	0.10
3l with $P_T^l > 20\ GeV$ in $\lvert\eta^l\rvert < 2.5$	1644	$7.7{\cdot}10^{-3}$	945	$4.4{\cdot}10^{-3}$
$P_T^{miss} > 30\ GeV$	129	$6.0{\cdot}10^{-4}$	80	$3.7{\cdot}10^{-4}$
2 jets with $\lvert\eta^{jet}\rvert < 2.5$	122	$5.7{\cdot}10^{-4}$	80	$3.7{\cdot}10^{-4}$
2 jets with $P_T^{jet} > 50\ GeV$	63	$2.9{\cdot}10^{-4}$	45	$2.1{\cdot}10^{-4}$
jets isolation: $\Delta R_{jj} > 0.4$	63	$2.9{\cdot}10^{-4}$	45	$2.1{\cdot}10^{-4}$
Lepton-jets isolation: $\Delta R_{lj} > 0.4$	42	$1.9{\cdot}10^{-4}$	31	$1.5{\cdot}10^{-4}$
Z mass $M_Z \pm 6\ GeV$	35	$1.6{\cdot}10^{-4}$	24	$1.1{\cdot}10^{-4}$
one tagged b jet in the event	24	$1.1{\cdot}10^{-4}$	10	$4.7{\cdot}10^{-5}$
t→Zq mass : $M_{Zq} \pm 8\ GeV$	0	0	0	0
t→Zq mass : $M_{Zq} \pm 12\ GeV$	0	0	0	0
t→Zq mass : $M_{Zq} \pm 24\ GeV$	1	$4.8{\cdot}10^{-6}$	0	0

Table 5. The numbers of events and efficiencies (%) of kinematical cuts applied in sequence for the Z+W background (leptonic mode) for $P_T^{jet} > 40$ GeV

C U T S	S E T 1		S E T 2	
	Events	Effic. (%)	Events	Effic. (%)
Number of generated events	35700		35700	
Preselection cuts	2941	8.2	2941	8.2
Lepton isolation cut: No track with $P_T > 2\ GeV$ in cone $\Delta R = 0.2$ (SET1); $\Delta R = 0.3$ (SET2)	2842	7.9	2630	7.4
3l with $P_T^l > 20\ GeV$ in $\|\eta^l\| < 2.5$	1920	5.4	1778	5.0
$P_T^{miss} > 30\ GeV$	1326	3.7	1252	3.5
2 jets with $\|\eta^{jet}\| < 2.5$	997	2.8	938	2.6
2 jets with $P_T^{jet} > 40\ GeV$	539	1.5	509	1.4
jets isolation: $\Delta R_{jj} > 0.4$	532	1.5	502	1.4
Lepton-jets isolation: $\Delta R_{lj} > 0.4$	532	1.5	502	1.4
Z mass $M_Z \pm 6\ GeV$	442	1.2	421	1.2
one tagged b jet in the event	32	0.09	28	0.08
t→Zq mass : $M_{Zq} \pm 8\ GeV$	5	$1.4{\cdot}10^{-2}$	5	$1.4{\cdot}10^{-2}$
t→Zq mass : $M_{Zq} \pm 12\ GeV$	7	$2.0{\cdot}10^{-2}$	6	$1.7{\cdot}10^{-2}$
t→Zq mass : $M_{Zq} \pm 24\ GeV$	8	$2.2{\cdot}10^{-2}$	7	$2.0{\cdot}10^{-2}$

Table 6. The numbers of events and efficiencies (%) of kinematical cuts applied in sequence for the Z+W background (leptonic mode) for $P_T^{jet} > 50$ GeV

C U T S	S E T 1		S E T 2	
	Events	Effic. (%)	Events	Effic. (%)
Number of generated events	35700		35700	
Preselection cuts	2941	8.2	2941	8.2
Lepton isolation cut: No track with $P_T > 2\ GeV$ in cone $\Delta R = 0.2$ (SET1); $\Delta R = 0.3$ (SET2)	2842	7.9	2630	7.4
3l with $P_T^l > 20\ GeV$ in $\|\eta^l\| < 2.5$	1920	5.4	1778	5.0
$P_T^{miss} > 30\ GeV$	1326	3.7	1252	3.5
2 jets with $\|\eta^{jet}\| < 2.5$	997	2.8	938	2.6
2 jets with $P_T^{jet} > 50\ GeV$	278	0.8	227	0.6
jets isolation: $\Delta R_{jj} > 0.4$	276	0.8	225	0.6
Lepton-jets isolation: $\Delta R_{lj} > 0.4$	276	0.8	225	0.6
Z mass $M_Z \pm 6\ GeV$	230	0.6	180	0.5
one tagged b jet in the event	19	0.05	28	0.04
t→Zq mass : $M_{Zq} \pm 8\ GeV$	1	$2.8{\cdot}10^{-3}$	1	$2.8{\cdot}10^{-3}$
t→Zq mass : $M_{Zq} \pm 12\ GeV$	1	$2.8{\cdot}10^{-3}$	1	$2.8{\cdot}10^{-3}$
t→Zq mass : $M_{Zq} \pm 24\ GeV$	2	$5.6{\cdot}10^{-3}$	2	$5.6{\cdot}10^{-3}$

Table 7. The numbers of events and efficiencies (%) of kinematical cuts applied in sequence for the $t\bar{t}$ background (leptonic mode) for $P_T^{jet} > 40$ GeV

C U T S	S E T 1		S E T 2	
	Events	Effic. (%)	Events	Effic. (%)
Number of generated events	$3.72{\cdot}10^6$		$3.72{\cdot}10^6$	
Preselection cuts	848160	29.4	848160	29.4
Lepton isolation cut: No track with $P_T > 2\ GeV$ in cone $\Delta R = 0.2$ (SET1); $\Delta R = 0.3$ (SET2)	93000	2.5	39432	1.1
3l with $P_T^l > 20\ GeV$ in $\lvert\eta^l\rvert < 2.5$	3378	$9.1{\cdot}10^{-2}$	1858	$5.0{\cdot}10^{-2}$
$P_T^{miss} > 30\ GeV$	3036	$8.2{\cdot}10^{-2}$	1600	$4.3{\cdot}10^{-2}$
2 jets with $\lvert\eta^{jet}\rvert < 2.5$	2902	$7.8{\cdot}10^{-2}$	1339	$3.6{\cdot}10^{-2}$
2 jets with $P_T^{jet} > 40\ GeV$	2604	$3.6{\cdot}10^{-2}$	1116	$2.0{\cdot}10^{-2}$
jets isolation: $\Delta R_{jj} > 0.4$	2604	$3.6{\cdot}10^{-2}$	1116	$2.0{\cdot}10^{-2}$
Lepton-jets isolation: $\Delta R_{lj} > 0.4$	1488	$4.0{\cdot}10^{-2}$	744	$1.4{\cdot}10^{-2}$
Z mass $M_Z \pm 6\ GeV$	186	$5.0{\cdot}10^{-3}$	50	$1.3{\cdot}10^{-3}$
one tagged b jet in the event	74	$2.0{\cdot}10^{-3}$	20	$5.4{\cdot}10^{-4}$
t→Zq mass : $M_{Zq} \pm 8\ GeV$	10	$2.7{\cdot}10^{-4}$	10	$2.7{\cdot}10^{-4}$
t→Zq mass : $M_{Zq} \pm 12\ GeV$	12	$3.2{\cdot}10^{-4}$	11	$3.0{\cdot}10^{-4}$
t→Zq mass : $M_{Zq} \pm 24\ GeV$	14	$3.8{\cdot}10^{-4}$	13	$3.5{\cdot}10^{-4}$

Table 8. The numbers of events and efficiencies (%) of kinematical cuts applied in sequence for the $t\bar{t}$ background (leptonic mode) for $P_T^{jet} > 50$ GeV

C U T S	S E T 1		S E T 2	
	Events	Effic. (%)	Events	Effic. (%)
Number of generated events	$3.72{\cdot}10^6$		$3.72{\cdot}10^6$	
Preselection cuts	848160	29.4	848160	29.4
Lepton isolation cut: No track with $P_T > 2\ GeV$ in cone $\Delta R = 0.2$ (SET1); $\Delta R = 0.3$ (SET2)	93000	2.5	39432	1.1
3l with $P_T^l > 20\ GeV$ in $\lvert\eta^l\rvert < 2.5$	3378	$9.1{\cdot}10^{-2}$	1858	$5.0{\cdot}10^{-2}$
$P_T^{miss} > 30\ GeV$	3036	$8.2{\cdot}10^{-2}$	1600	$4.3{\cdot}10^{-2}$
2 jets with $\lvert\eta^{jet}\rvert < 2.5$	2902	$7.8{\cdot}10^{-2}$	1339	$3.6{\cdot}10^{-2}$
2 jets with $P_T^{jet} > 50\ GeV$	1339	$3.6{\cdot}10^{-2}$	740	$2.0{\cdot}10^{-2}$
jets isolation: $\Delta R_{jj} > 0.4$	1332	$3.6{\cdot}10^{-2}$	736	$2.0{\cdot}10^{-2}$
Lepton-jets isolation: $\Delta R_{lj} > 0.4$	1012	$2.7{\cdot}10^{-24}$	596	$1.6{\cdot}10^{-2}$
Z mass $M_Z \pm 6\ GeV$	104	$2.8{\cdot}10^{-3}$	29	$7.8{\cdot}10^{-4}$
one tagged b jet in the event	45	$1.2{\cdot}10^{-3}$	10	$2.7{\cdot}10^{-4}$
t→Zq mass : $M_{Zq} \pm 8\ GeV$	3	$8.1{\cdot}10^{-5}$	3	$8.1{\cdot}10^{-5}$
t→Zq mass : $M_{Zq} \pm 12\ GeV$	5	$1.3{\cdot}10^{-4}$	4	$1.1{\cdot}10^{-4}$
t→Zq mass : $M_{Zq} \pm 24\ GeV$	6	$1.6{\cdot}10^{-4}$	5	$1.3{\cdot}10^{-4}$

Table 9. The estimated Branching ratios $t \to Zq$ $(q = c, u)$ for leptonic mode

			S E T 1	S E T 2
Br(t→Zq)	$P_T^{jet} > 40$ GeV	$m_{Zq} \pm 8$ GeV	$1.91 \cdot 10^{-4}$	$2.07 \cdot 10^{-4}$
		$m_{Zq} \pm 12$ GeV	$1.65 \cdot 10^{-4}$	$1.69 \cdot 10^{-4}$
		$m_{Zq} \pm 24$ GeV	$1.35 \cdot 10^{-4}$	$1.36 \cdot 10^{-4}$
	$P_T^{jet} > 50$ GeV	$m_{Zq} \pm 8$ GeV	$1.32 \cdot 10^{-4}$	$1.44 \cdot 10^{-4}$
		$m_{Zq} \pm 12$ GeV	$1.21 \cdot 10^{-4}$	$1.20 \cdot 10^{-4}$
		$m_{Zq} \pm 24$ GeV	$1.12 \cdot 10^{-4}$	$1.11 \cdot 10^{-4}$

Table 10. The numbers of events and efficiencies (%) of kinematical cuts applied in sequence for the signal (hadronic mode).

C U T S	Events	Effic. (%)
Number of generated events	19002	
Preselection cuts	8742	46.0
2l with $P_T^l > 20\ GeV$ in $\lvert\eta^l\rvert < 2.5$	7174	37.7
4 jets with $P_T > 50\ GeV$ in $\lvert\eta^{jet}\rvert < 2.5$	2896	15.2
jets isolation: $\Delta R_{jj} > 0.4$	2828	14.9
Lepton-jets isolation: $\Delta R_{lj} > 0.4$	2826	14.9
Z mass $M_Z \pm 6\ GeV$	2426	12.8
W mass $M_W \pm 16\ GeV$	1006	5.3
one tagged b jet in the event	432	2.2
t→Wb mass: $M_{Wb} \pm 8\ GeV$	106	0.6
t→Zq mass : $M_{Zq} \pm 8\ GeV$	46	0.2
t→Zq mass : $M_{Zq} \pm 12\ GeV$	58	0.3
t→Zq mass : $M_{Zq} \pm 24\ GeV$	74	0.4

Table 11. The numbers of events and efficiencies (%) of kinematical cuts applied in sequence for the Z+jets background (hadronic mode).

C U T S	Events	Effic. (%)
Number of generated events	$21.4{\cdot}10^6$	
Preselection cuts	746259	3.5
2l with $P_T^l > 20\ GeV$ in $\lvert\eta^l\rvert < 2.5$	592627	2.8
4 jets with $P_T > 50\ GeV$ in $\lvert\eta^{jet}\rvert < 2.5$	63478	0.29
jets isolation: $\Delta R_{jj} > 0.4$	60421	0.28
Lepton-jets isolation: $\Delta R_{lj} > 0.4$	60394	0.28
Z mass $M_Z \pm 6\ GeV$	50973	0.24
W mass $M_W \pm 16\ GeV$	14170	$6.6{\cdot}10^{-2}$
one tagged b jet in the event	1379	$6.4{\cdot}10^{-3}$
t→Wb mass: $M_{Wb} \pm 8\ GeV$	90	$4.2{\cdot}10^{-4}$
t→Zq mass : $M_{Zq} \pm 8\ GeV$	0	0
t→Zq mass : $M_{Zq} \pm 12\ GeV$	1	$4.8{\cdot}10^{-6}$
t→Zq mass : $M_{Zq} \pm 24\ GeV$	2	$9.3{\cdot}10^{-6}$

Table 12. The numbers of events and efficiencies (%) of kinematical cuts applied in sequence for the Z+W background (hadronic mode).

C U T S	Events	Effic. (%)
Number of generated events	121000	
Preselection cuts	4970	4.1
2l with $P_T^l > 20\ GeV$ in $\|\eta^l\| < 2.5$	4456	3.7
4 jets with $P_T > 50\ GeV$ in $\|\eta^{jet}\| < 2.5$	400	0.3
jets isolation: $\Delta R_{jj} > 0.4$	390	0.3
Lepton-jets isolation: $\Delta R_{lj} > 0.4$	361	0.3
Z mass $M_Z \pm 6\ GeV$	268	0.2
W mass $M_W \pm 16\ GeV$	139	0.1
one tagged b jet in the event	11	$9.1 \cdot 10^{-3}$
t$\rightarrow$Wb mass: $M_{Wb} \pm 8\ GeV$	1	$8.3 \cdot 10^{-4}$
t$\rightarrow$Zq mass : $M_{Zq} \pm 8\ GeV$	0	0
t$\rightarrow$Zq mass : $M_{Zq} \pm 12\ GeV$	0	0
t$\rightarrow$Zq mass : $M_{Zq} \pm 24\ GeV$	0	0

Table 13. The relative efficiencies (%) of some kinematical cuts
for leptonic and hadronic modes of the signal.

C U T S	LEPTONIC MODE	HADRONIC MODE
	Rel.Effic. (%)	Rel.Effic. (%)
3l with $P_T^l > 20\ GeV$ in $\|\eta^l\| < 2.5$	70.1	
2l with $P_T^l > 20\ GeV$ in $\|\eta^l\| < 2.5$		82.0
2 isolated jets with $P_T^{jet} > 50\ GeV$	48.6	
4 isolated jets with $P_T^{jet} > 50\ GeV$		39.4
Lepton-jets isolation: $\Delta R_{lj} > 0.4$	94.0	99.0
Z mass $M_Z \pm 6\ GeV$	84.9	85.8
one tagged b jet in the event	48.6	42.9
t→Zq mass : $M_{Zq} \pm 8\ GeV$	43.4	43.4
t→Zq mass : $M_{Zq} \pm 12\ GeV$	49.2	54.7
t→Zq mass : $M_{Zq} \pm 24\ GeV$	75.3	69.8

Table 14. The estimated Branching ratios $t \rightarrow Zq$ ($q = c, u$) for for hadronic mode.

Br(t→Zq)	$P_T^{jet} > 50$ GeV	$m_{Zq} \pm 8$ GeV	$2.86{\cdot}10^{-4}$
		$m_{Zq} \pm 12$ GeV	$2.20{\cdot}10^{-4}$
		$m_{Zq} \pm 24$ GeV	$2.30{\cdot}10^{-4}$

Table 15. The estimated Branching ratios $t \to Zq$ $(q = c, u)$ for combined leptonic and hadronic modes.

			S E T 1	S E T 2
Br(t→Zq)	$P_T^{jet} > 50$ GeV	$m_{Zq} \pm 8$ GeV	$0.95 \cdot 10^{-4}$	$1.01 \cdot 10^{-4}$
		$m_{Zq} \pm 12$ GeV	$0.94 \cdot 10^{-4}$	$0.93 \cdot 10^{-4}$
		$m_{Zq} \pm 24$ GeV	$0.90 \cdot 10^{-4}$	$0.88 \cdot 10^{-4}$

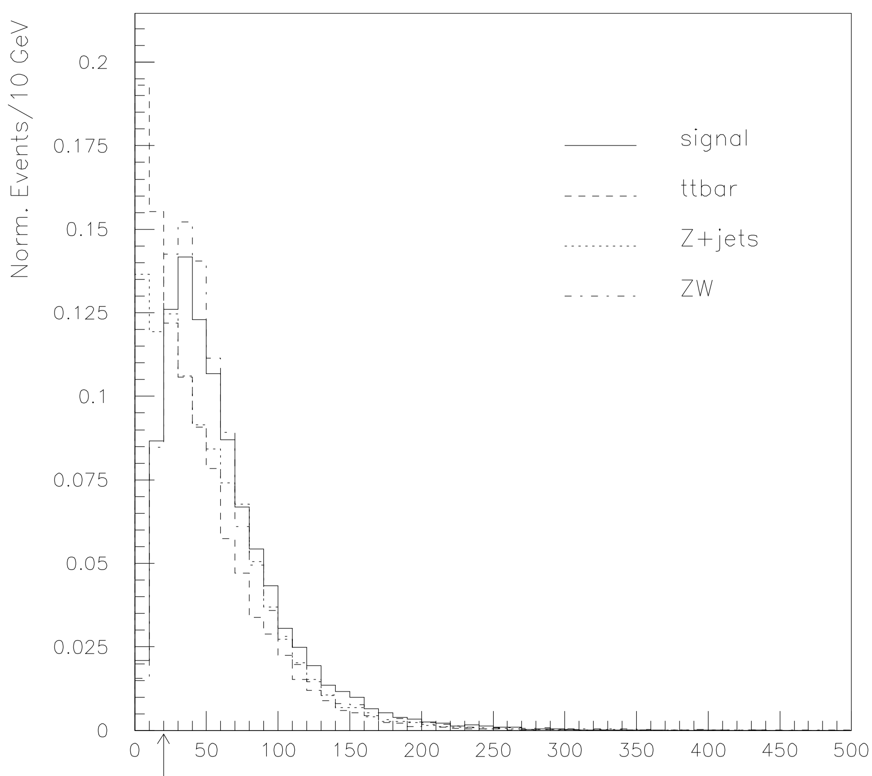

Figure 1: The P_T distributions of leptons that recostruct Z mass ,for leptonic mode signal and backgrounds, normalised to unity. The arrow indicates the threshold value P_T^l for kinematical cut.

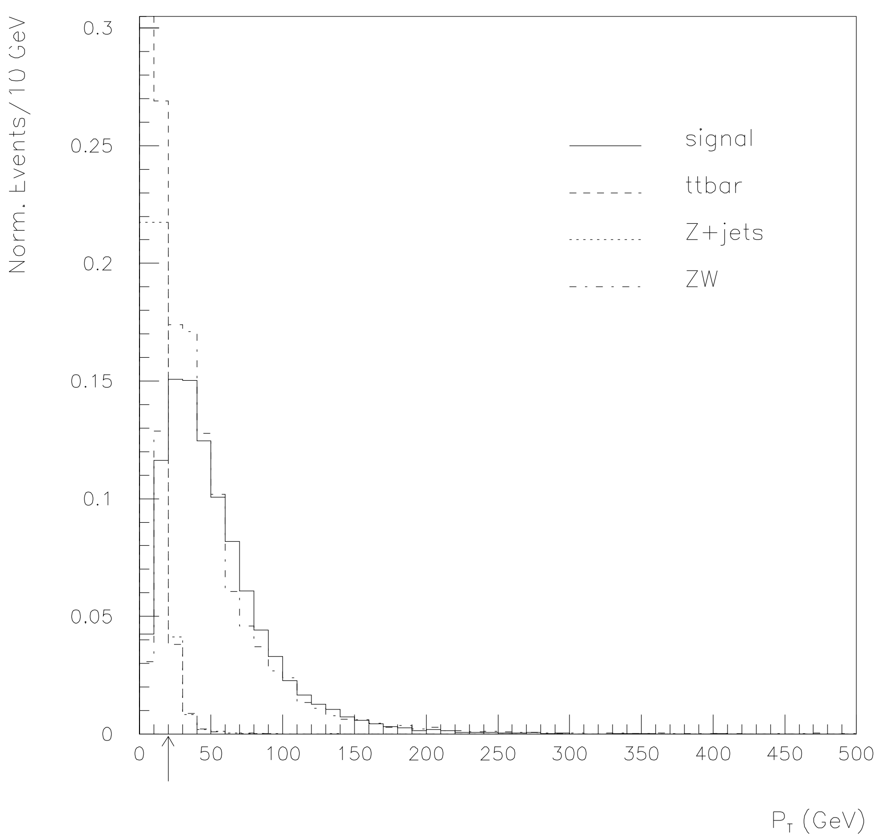

Figure 2: The third lepton P_T distributions for leptonic mode signal and backgrounds, normalised to unity. The arrow indicates the threshold value P_T^l for kinematical cut.

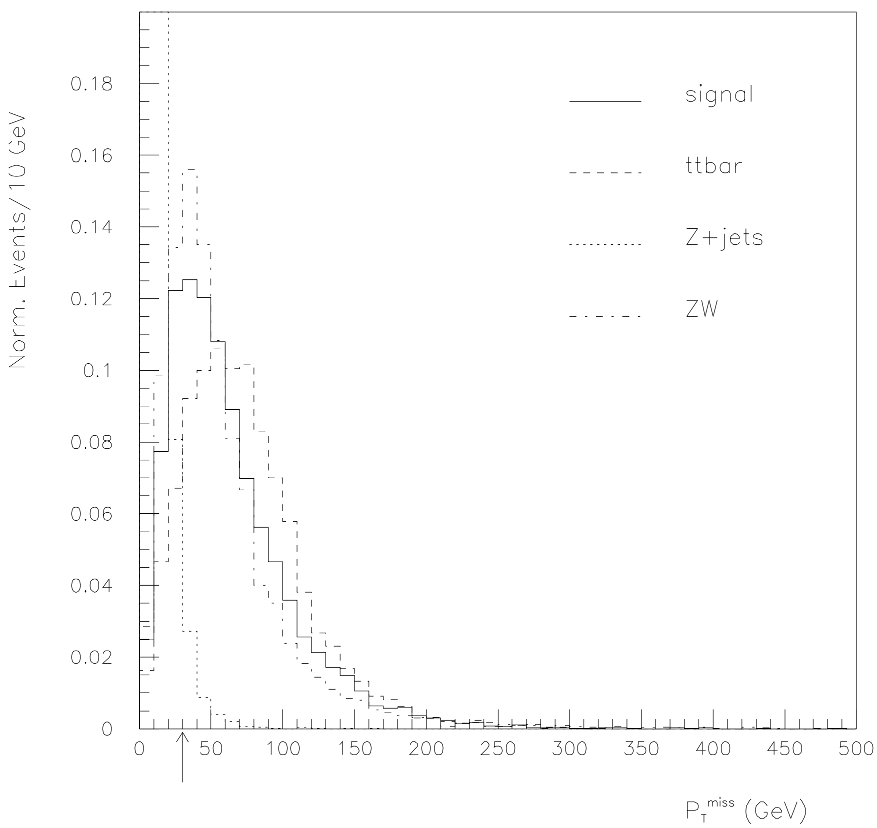

Figure 3: The reconstructed P_T^{miss} distributions for leptonic mode signal and backgrounds, normalised to unity. The arrow indicates the threshold value P_T^{miss} for kinematical cut.

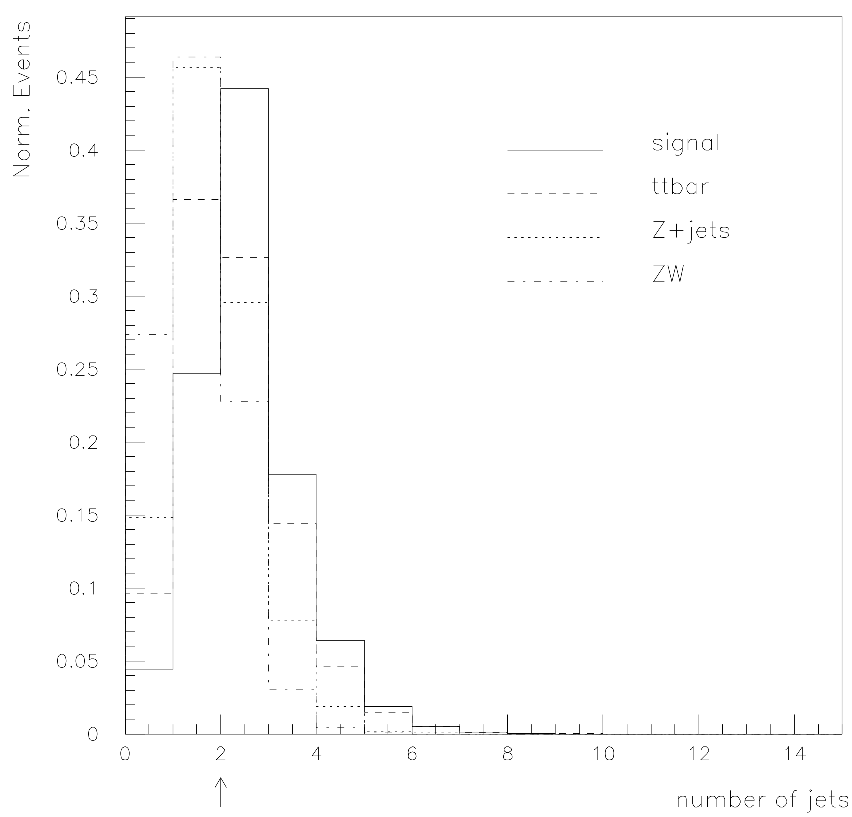

Figure 4: Distribution of jet multiplicity (threshold at $P_T^{jet} > 50\ GeV$) for signal and backgrounds, normalised to unity. The arrow indicates the threshold value of the number of jets for kinematical cut.

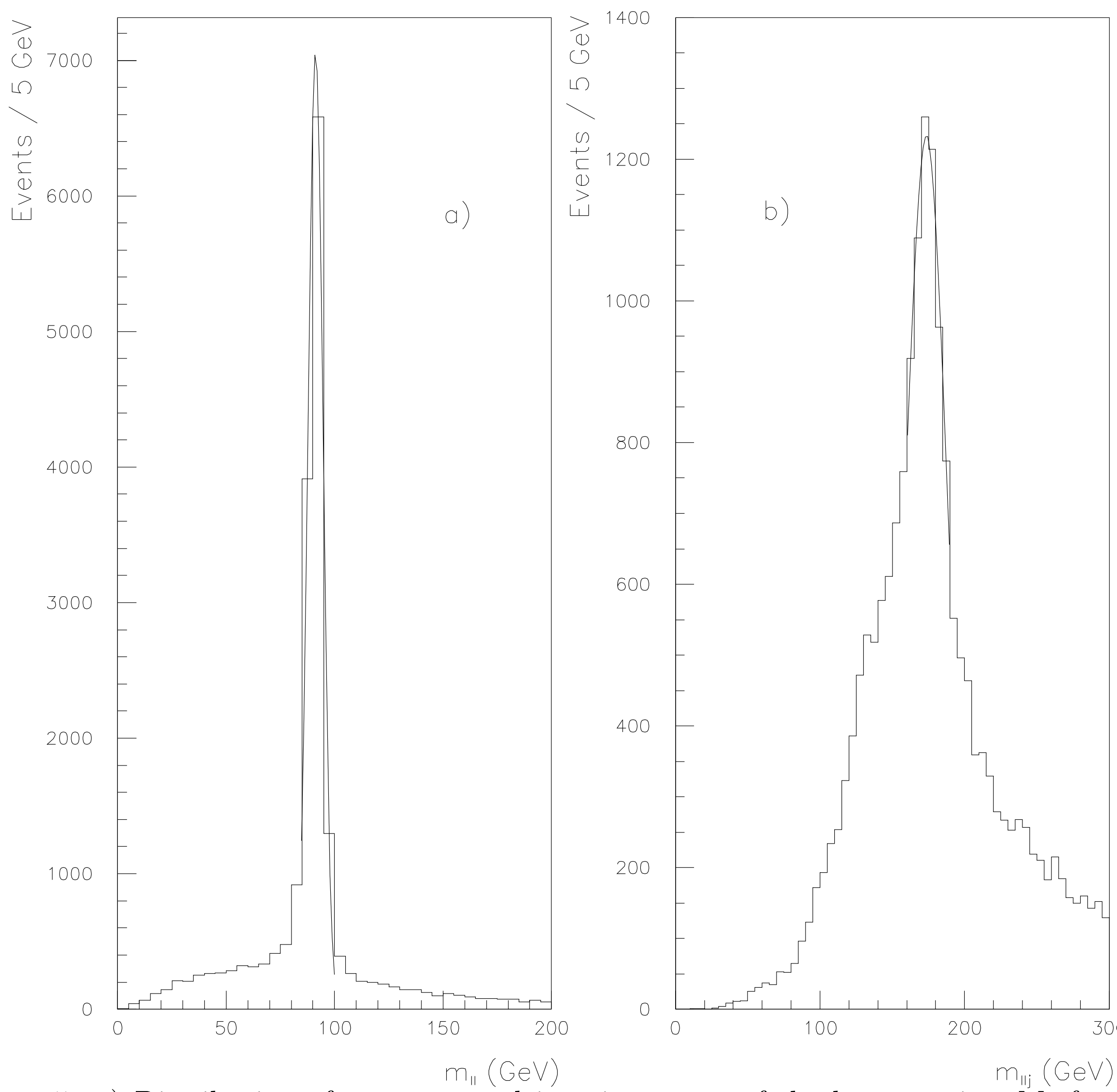

Figure 5: a) Distribution of reconstructed invariant mass of the lepton pairs, M_{ll} for the leptonic mode. b) Distribution of reconstructed invariant mass of $t \to llj$ for the leptonic mode.

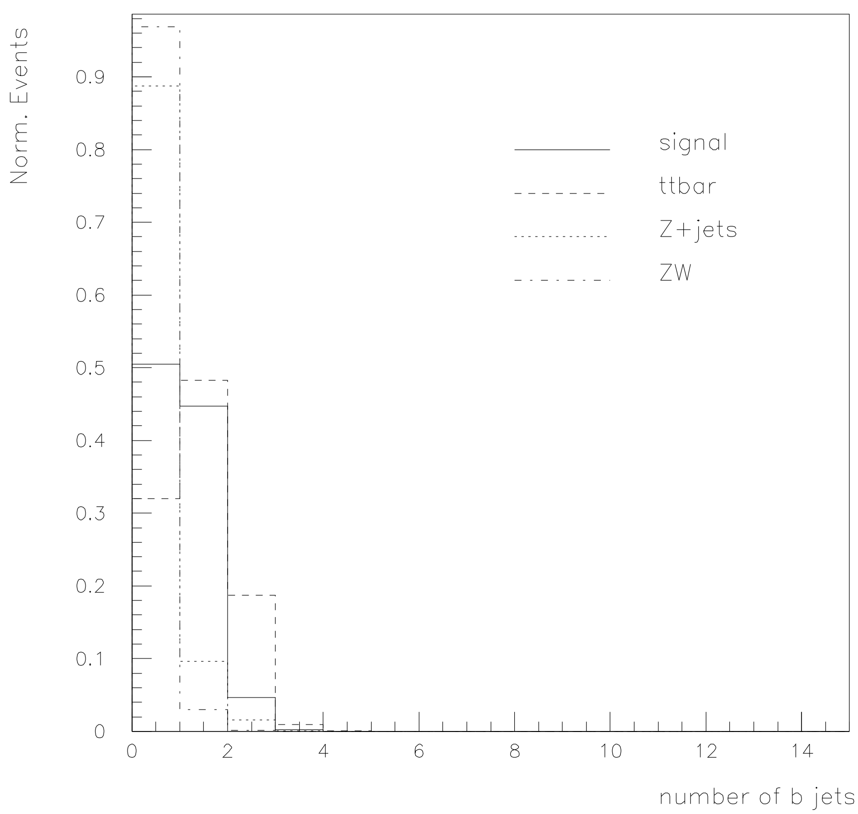

Figure 6: Distribution of b-jet multiplicity (threshold at $P_T^{jet} > 50\ GeV$) for signal and backgrounds, normalised to unity.

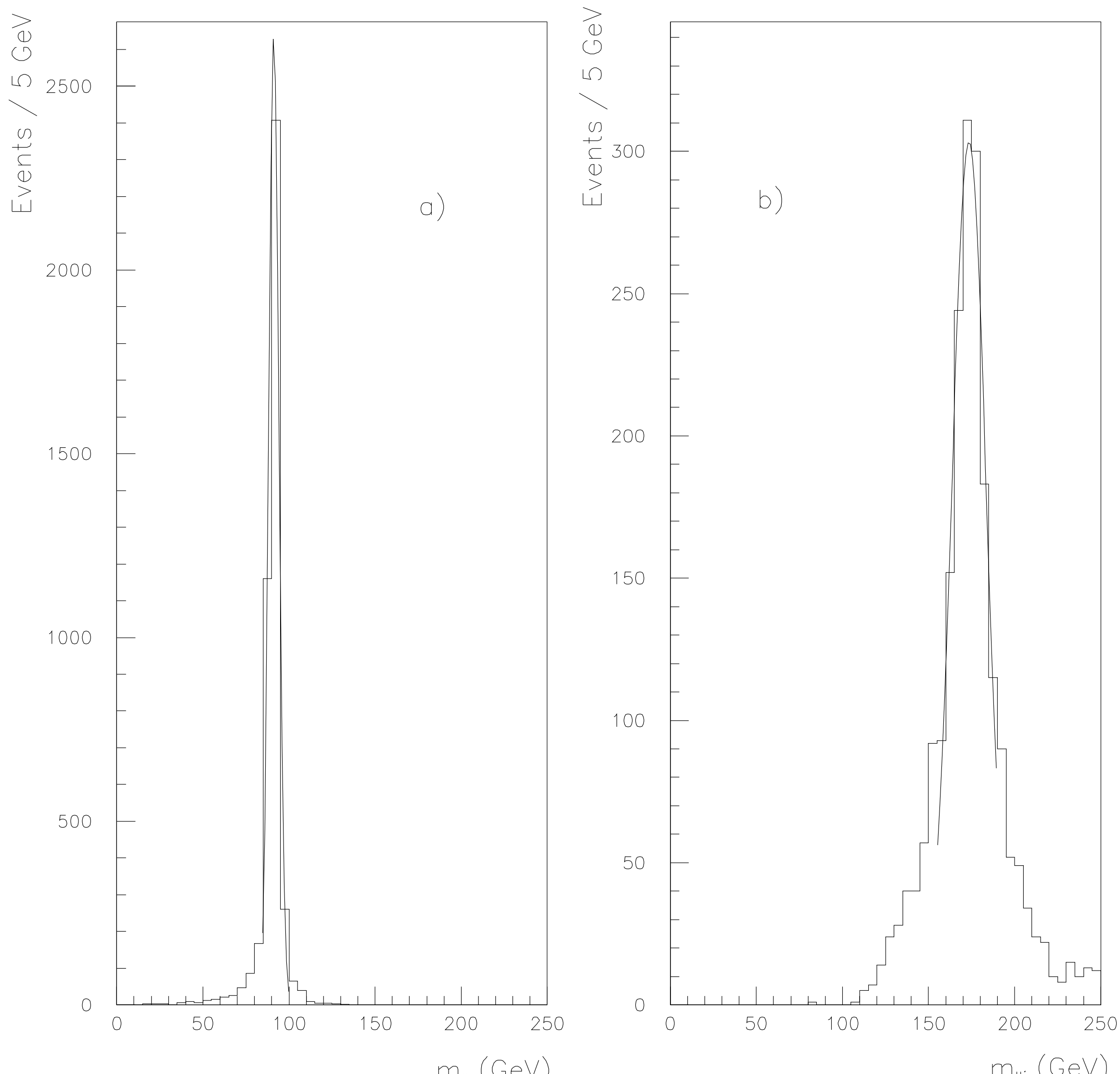

Figure 7: a) Distribution of reconstructed invariant mass of the lepton pairs, M_{ll} for the best combination (hadronic mode). b) Distribution of reconstructed invariant mass of $t \rightarrow llj$ for the best combination of llj (hadronic mode).

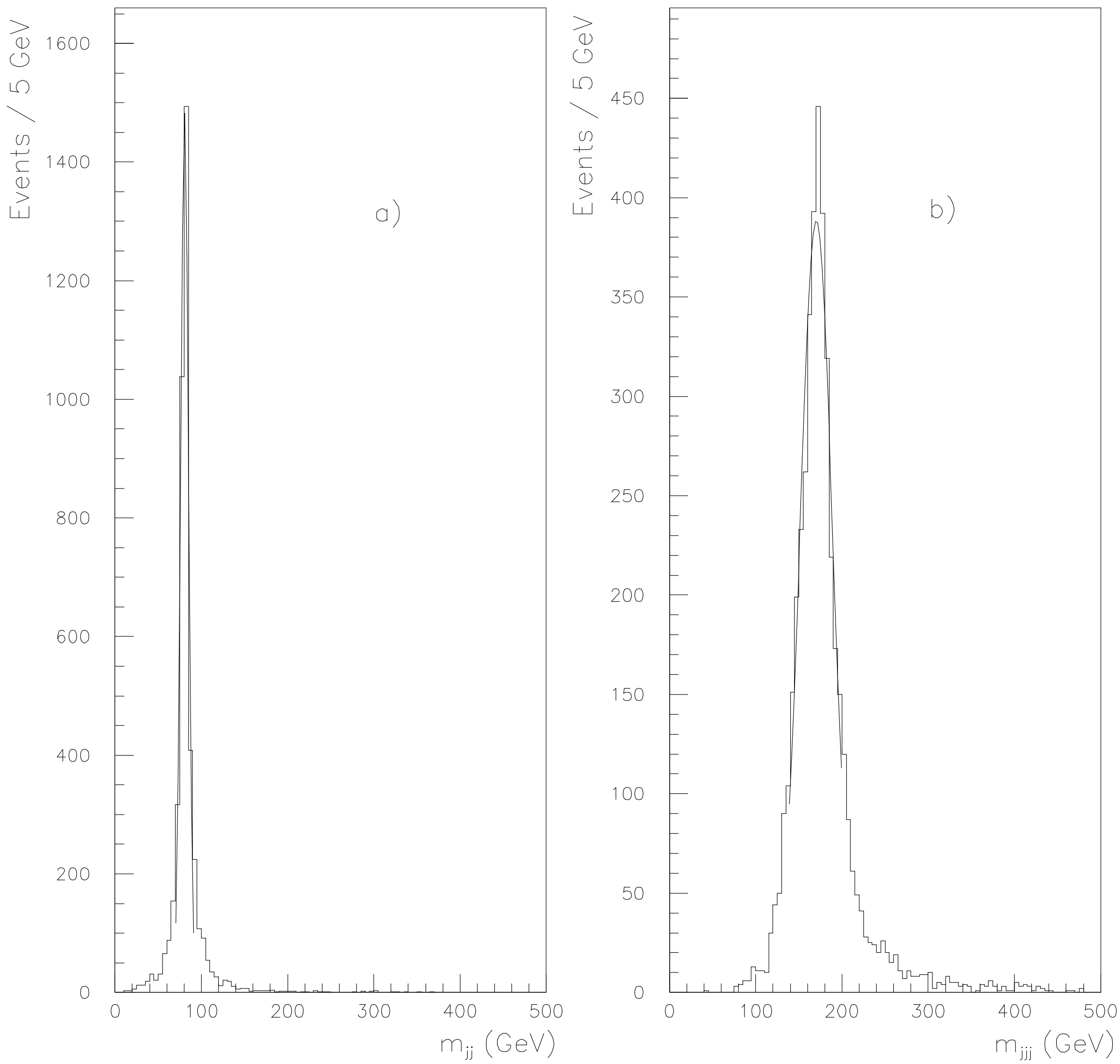

Figure 8: a) Distribution of reconstructed invariant mass of the jet pairs, M_{jj} for the best combination (hadronic mode). b) Distribution of reconstructed invariant mass of $t \rightarrow jjj_b$ for the best combination of jjj_b (hadronic mode).